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EFFECTIVENESS OF NASA 1032 & 1035 AND AIR FORCE 1030 & 1034 SUITS IN PROTECTION AGAINST COLD WATER HYPOTHERMIA

Annette C. Drew, Jonathan W. Kaufman, and Gregory K. Askew
Air Vehicle and Crew Systems Technology Department (Code 6023)
NAVAL AIR WARFARE CENTER-AIRCRAFT DIVISION
Warminster, PA 18974-5000

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Annette C. Drew, Jonathan W. Kaufman, and
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13. ABSTRACT *(Maximum 200 words)*

Our lab examined the relative cold exposure protection afforded by two sets of clothing ensembles. One set consisted of National Aeronautics and Space Administration suits (NASA1032 and NASA1035) and the other consisted of Air Force suits (AF1030 and AF1034). Eight healthy male subjects wearing these ensembles were exposed on four separate occasions to cold water (T_{water} = 4.4°C) in an environmentally controlled chamber with cold ambient air temperature (T_{air} = 5.6°C). Each subject tested either a NASA or an Air Force set of clothing ensembles for the ability to keep body core temperature (T_{re}) above 35°C (onset of hypothermia) in both head-out immersion and enclosed within a raft. Subjects in the NASA suits were given up to 6 hours for the immersion trials and 24 hours for the raft trials, although none of the subjects in either suit were able to endure the entire duration of the experiments due to a variety of reasons. The NASA 1032 appeared to perform better than the NASA1035 in both immersion and raft trials as none of the NASA1032 subjects' T_{re} fell to 35°C and the mean change in T_{re} (ΔT_{re}) was somewhat smaller in the NASA1032 ($p<0.06$). Both NASA1032 and NASA1035 subjects

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showed comparable mean exposure duration times. The subject with the lowest percentage body fat of all those participating in the NASA study (12.4%) reached T_{re}=35°C in both the NASA1035 immersion and raft trials far before the scheduled end of these trials. Both Air Force immersion and raft trials were scheduled for 2 hours of cold water exposure. The AF1034 was more successful than the AF1030 suit at keeping subject T_{re} above 35°C based on the fact that all but one subject was able to complete the entire two hours intended while wearing the AF1034. This one subject had the lowest percentage body fat (13%) of all who participated in the Air Force study, and was performing an AF1034 immersion trial when he reached T_{re}=35°C at minute 116. On the other hand, three of the four subjects terminated at least one of their AF1030 trials due to T_{re}=35°C . Only the AF subject of highest percentage body fat (22%) was able to complete all trials without falling below 35°C.

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INTRODUCTION

Within the last few years, the National Aeronautics and Space Administration (NASA) has identified the need to provide expanded Space Shuttle crew protection. Suits have been developed with the integrated functions of protection against extreme hypobaria, gravitational stress, and environmental exposure. These suits are similar to ones developed for the U.S. Air Force (AF) for high altitude aircraft. The Environmental Physiology Laboratory at the Naval Air Development Center performed a pair of studies evaluating the thermal protection afforded by various AF and NASA flight suits under simulated rough, raining, open sea conditions both with and without a modified U.S. Navy one-man raft. These are conditions which might be encountered by downed shuttle flight crew. One study evaluated the NASA1032 and NASA1035 suits and the other examined a set of U.S. Air Force suits (AF1030 and AF 1034). This paper describes comparisons made between the two NASA suits and also between the two Air Force suits. Also examined was the value of a raft in exposure survival.

MATERIALS

Four types of suits were tested in these studies (Table 2). The NASA suits consist of a laminated Goretex membrane shell which allows for the passage of water vapor but not liquid, with pressure bladders and control devices designed to counter loss of cabin pressure. Specifically, the NASA 1035 suit is a full pressure suit with no integrated anti-gravitational protection, whereas the NASA 1032 suit is a partial pressure suit with bladders which cover all but the feet and joints. In addition, the NASA 1032 suit provides integrated anti G protection. All ensembles included some common garments and ancillary equipment (Table 1). The Air Force (AF) suits were similar in design to the NASA suits. The AF1030 suit has many layers, whereas the AF1034 suit has fewer layers and has a final outer layer of Nomex. Both AF suits are full pressure suits.

In the raft trials, a modified U.S. Navy LRU-18/U type inflatable one-man raft was employed. The modification consisted of a raft canopy composed of two large flaps of water-proof fabric running the length of the raft, with a drawstring hood at one end for sealing the head with the face exposed. A continuous 2" velcro strip held the flaps together at the midline, thus sealing off the subject's body from the environment. While the raft canopy was an effective means of removing large quantities of water from the raft, there were two supplemental bailing systems connected to the raft, each to be used at a different stage of raft water removal. A small, wedge- shaped scoop with a square shaped opening and a 1.2 liter volume was tethered to the raft. This scoop had a fitted strap which was designed to slip over a survival mitten. Moderate quantities of trapped water resulting from raft boarding could be bailed relatively quickly. To complete the removal of water, a small hand pump was also provided which consisted of clear tubing connected to a squeeze bulb. This apparatus enabled the subject to remove smaller quantities of water but had the advantage of allowing the canopy to remain closed while pumping out water, retaining metabolic heat within the raft. The importance of an efficient bailing system was made clear in an earlier study (9).

METHODS

Subjects: After being fully informed of the experimental protocol and associated risks, eight healthy male subjects (four for the NASA suits and four for the Air Force suits) volunteered for both studies. The subjects were then scheduled at large enough intervals of time between trials (2 days) such that the chances for acclimatization were reduced. Subjects were required to

TABLE 1: Common clothing and equipment used in the Air Force and NASA studies

Undergarments	Outergarments/Equipment
capilene underwear	parachute harness
polypropylene socks	parachute container (empty)
wool socks	communications carrier assembly
disposable aborption collection device	life raft
cotton gloves	flight gloves
	survival mittens
	flyers boots
	personal flotation device
	helmet

Table 2: Characteristics of garments used in the Air Force and NASA studies.

AF1030 Suit	AF1034 Suit
Older suit	Newer suit
Many layers, heavy	Less bulky, less material
Full pressure suit	Full pressure suit
defective zipper	Bladder layer of Goretex (breathable)
	No integrated anti-G protection
	water-proof zipper

NASA1032 Suits	NASA 1035 Suits
Older suit	Newer suit
Many layers, heavy	Less bulky, less material
Partial pressure suit	Full pressure suit
Pressure bladders consist of 2 layers of urethane coated nylon	Bladder layer of Goretex(breathable)
Outer layer of Nomex	No integrated anti-G protection
Integrated anti-G protection bladder	

participate in raft-boarding training to assure smooth trials involving the raft.

Each subject tested two suits (Table 3), in head-out immersion using only a personal flotation device and also with a raft for a total of four exposures per subject. Subject weight and height were recorded at the beginning of every trial and the mean for each subject calculated. Percent body fat was determined from estimates of body density (2), which were computed from skin fold measurements (Table 4) obtained with Lange skinfold calipers (Cambridge Scientific Inc., Cambridge MA.) using the equations of Lohman (3). Body fat measurements were calculated from impedance measurements (Bodycomp analyzer Model# BIA-101, R.J.L Systems, Inc.) for comparison . Body surface area (S.A.) was calculated from subject weight and height.

On the day of the trial, the subject provided a urine sample and inserted a pair (for redundant signals) of rectal thermocouples (Sensortek, Clifton,NJ, model RET-1) at least 8 -10 cm. anterior to the anal sphincter An attending flight surgeon provided a physical examination, including a urinalysis. ECG electrodes (3M, Minneapolis,MN, Red Dot) were then placed on the subject, providing signals which were amplified with isolated ECG amplifiers (Gould, Cleveland, Ohio, model 4600 series amplifiers). Heat flux/temperature transducers, consisting of a thermopile heat flux transducer with a thermistor located in the center (Hamburg Associates, Jupiter, FL), were taped to the following 10 body sites: (A) forehead; (B) left upper chest; (C) left distal upper arm; (D) dorsum of left hand; (E) right anterior thigh; (F) left posterior thigh; (G) right shin; (H) dorsum of right foot; (J) right proximal upper arm; and (K) left lower back. Throughout the experiment, analog signals from these transducers were amplified (Bioinstrumentation Assoc., San Diego, CA model HF-12/Temp-14) and stored on the laboratory's data collection system (MDB Systems, Orange, CA model MLSI-1123C-R-X; Data Translations, Marlboro, MA, DT2782 A/D boards).

The subject was then dressed in the appropriate clothing ensemble for that scheduled trial. Laboratory temperatures was maintained at approximately 20°C (68°F) to minimize thermal stress during dressing. On the external surface of the suits, a type T thermocouple was placed on the upper chest to measure ambient air temperature throughout the trial. Upon completion of dressing, subjects in NASA suits were cooled with a ventilator for twenty minutes to enable body temperatures and heart rate to stabilize. As the AF suits were not equipped with ventilation systems, a rest period was not imposed when they were used.

The subject then entered the environmental chamber ($T_{air} = 5.6 \pm 0.1$°C) and climbed into the pool ($T_{water} = 4.4 \pm 0.2$°C). To enhance simulation of harsh open sea conditions, overhead spray, approximately 1 foot waves, and wind of velocity 6.7 to 11.7 km/hr were employed. Subjects in the immersion trials used only a personal flotation device which kept them immersed up to the neck. Raft trials required subjects to float in the water for an initial period of 5 minutes, after which they were handed a raft with its primary air chambers inflated. The subject then boarded the raft and inflated the secondary air chambers with a CO_2 cartridge. Once the raft was fully inflated,the subject used the canopy flaps to scoop large amounts of water out of the raft before partially sealing the canopy along the velcro midline and initiating bailing with the scoop. Another type T thermocouple was then passed through a small opening of the canopy onto the bottom of the raft to measure temperature changes of any remaining raft water. The final stage of bailing using the hand pump was begun after complete closure of the raft canopy, and continued until the subject decided that a sufficient amount of water has been removed.

Table 3: Experimental Design

Subjects AF1, AF2, AF3, AF4 utilized the following suits and configurations:

	Suit Type	Configuration	Alloted Time
(1)	AF1030	IMMERSION	2 Hours
(2)	AF1030	RAFT	2 Hours
(3)	AF1034	IMMERSION	2 Hours
(4)	AF1034	RAFT	2 Hours

Subjects NASA1, NASA2, NASA3, NASA4 utilized the following suits and configurations:

	Suit Type	Configuration	Alloted Time
(1)	NASA1032	IMMERSION	6 Hours
(2)	NASA1032	RAFT	24 Hours
(3)	NASA1035	IMMERSION	6 Hours
(4)	NASA1035	RAFT	24 Hours

Note: The differences in alloted times are based on specifications set by the Air Force and NASA (see report)

Table 4: Physical Characteristics of the Subjects

SUBJECTS IN NASA SUITS

	AGE (years)	HEIGHT (inches)	WEIGHT (pounds)	%FAT (skin fold thickness)	S.A. (in. x in.)
NASA1	31	73	158	12.42	1.95
NASA2	35	70	197	21.66	2.08
NASA3	37	74.25	171	13.74	2.04
NASA4	25	66	145	20.95	1.75
mean	32.00	70.81	167.75	17.19	1.96
sem	5.29	3.67	22.20	4.79	0.15

SUBJECTS IN AIRFORCE SUITS

	AGE (years)	HEIGHT (inches)	WEIGHT (pounds)	%FAT(SKN) (skin fold thickness)	S.A. (in. x in.)
AF1	48	65.5	141.5	16.25	1.72
AF2	28	68	139	14.5	1.75
AF3	32	70.25	202.25	22.12	1.81
AF4	38	67	136	13.34	1.72
mean	36.50	67.69	154.69	16.55	1.75
sem	8.70	1.99	31.79	3.90	0.04

Subjects were instructed to try to remain in the raft for 24 hours during NASA trials and for 2 hours during AF trials. The AF immersions trials were also scheduled to last for 2 hours, while the NASA immersions were allotted 6 hours. No food was available during any of the experiments, but packets of potable water were provided during the NASA raft trials.

Experiments were terminated early due to any one of the following circumstances: (i) the subject's rectal temperature falls to 35°C and stays there for 3 minutes; (ii) the subject's rectal temperature falls below 35°C; (iii) the subject's finger or toe temperature falls to 10°C for 3 minutes; (iv) the subject's finger or toe temperature falls below 10°C; (v) heart rate exceeds 90% of the maximum predicted for the subject's age; (vi) failure of devices or signals used for subject safety; or (vii) the subject, attending flight surgeon, or principal investigator requests termination due to any reason including (but not limited to) considerable patient discomfort, medical emergency, hunger or exhaustion.

The subject was continuously monitored throughout the trial by a flight surgeon and two emergency medical technicians, one inside the chamber and the other with the flight surgeon at a display which showed core (rectal), toe, and finger temperatures and EKG signals. The subject at all times had direct 2-way communication with both monitors. The subject was asked to give a numerical response which rated his comfort, shivering level, coldness, and fatigue every 10 to 20 minutes, and whenever else it was deemed necessary.

DATA ANALYSIS

For both the AF and NASA studies, the Wilcoxon Signed Rank Test, a non-parametric version of the T-test, was performed between the results of each suit pair (i.e, AF1030 vs. AF1034, NASA1032 vs. NASA1035) for both raft and immersion configurations. Means, standard deviations, standard errors of the means, and variances were computed for the following parameters; elapsed exposure time (t_T), perceived shivering scores, change in T_{re} over the course of a trial (ΔT_{re}), and the rate of change of T_{re} over the elapsed exposure time ($\Delta T_{re}/t_T$). All p values reported in this study are from Wilcoxon Signed Rank Tests. Differences were were considered significant at $p < 0.05$ and potentially significant at $p < 0.10$. Potential significance is included because of the small sample sizes used in the analyses.

A simple linear extrapolation was examined in an attempt to estimate the amount of time in which subjects *might* have stayed in the cold water and avoided hypothermia. These extrapolations did not attempt to predict T_{re}; they were used only as a means to estimate the time required for subjects' T_{re} to reach 35°C. The extrapolations were based on "quasi-steady state" rates of T_{re} drop of 0.002°C/min. and 0.001°C/min., with extrapolated times to a termination point of T_{re} = 35.0°C based on subjects' T_{re} at the end of their actual trials. These rates were chosen because they represent the smallest non-zero $\Delta T_{re}/t_T$ observed in either study.

RESULTS

A "typical" cooling curve for subjects in these clothing and environmental test conditions can be summed up as follows (Figure 1): (i) a brief period of stable (or slightly rising) baseline core temperatures before entering the water, (ii) a rise in core temperature upon entering the water resulting from the onset of vasoconstriction of blood vessels in the extremities which increases deep body core blood volume. Next (iii), a sharp, downward drop of core temperature over time following maximum heat transfer to the core due to a cooling of the skin, and (iv) a long period of quasi-steady state which may include transient periods of increase or decrease. In many

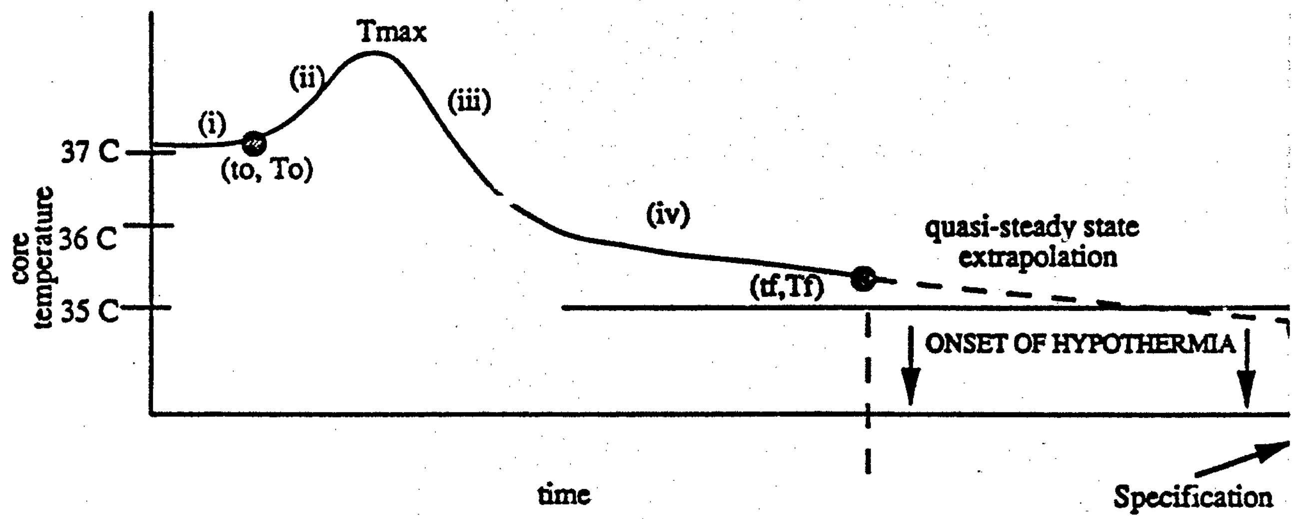

Figure 1. Typical rectal temperature curve after exposure to cold water in a protective garment. The vertical scale is distorted in order to identify portions of the cooling curve. The increase in rectal temperature at the beginning of an exposure is normally on the order of 0.2 C. Clinical hypothermia is defined as a core temperature below 35 C.

subjects this period is marked by a slow decline in core temperature overall. Vasoconstriction continues throughout cold exposure. If any of the subjects were to have tolerated the cold long enough to exhaust their glycogen stores (the point of physical exhaustion), it is reasonable to expect a sharp temperature drop at this point due to vasodialation and the lack of shivering. Graphs from both the AF and NASA suits are shown (Figures 2 - 9).

The NASA1032 was able to prevent all of the subject's T_{re} from reaching 35°C in both immersion and raft trials. In contrast, the NASA1035 could not prevent the NASA subject of lowest body fat (12.4%) from reaching a $T_{re} = 35°C$ in less than 4 hours in either the immersion or raft trials (Table 5). The mean ΔT_{re} of the NASA1032 immersion trials tended to be lower than the NASA1035 trials ($p < 0.06$) (Table 5). None of the subjects in either the NASA1032 or NASA1035 were willing to endure the entire 6 hours or 24 hours for immersion or raft trials, respectively. In immersion trials, subjects were able to tolerate their environment for up to 286 and 187 minutes in the NASA1032 and NASA1035, respectively (Table 5). Immersion trials in the NASA1032 tended to last longer than in the NASA1035 ($p < 0.06$). The NASA1032 allowed subjects to tolerate raft trials for as long as 617.5 while the NASA1035 enabled subjects to endure exposure times of up to 666 minutes (Table 5). The difference in mean exposure duration is deceiving, however, because subject NASA4 terminated his NASA1032 raft trial primarily due to anxiety associated with his first experience of long-term immersion in cold water. No change in T_{re} was observed after this comparatively short trial. All of his subsequent trials were of greater duration, indicating his greater confidence. By eliminating his raft exposure duration data, the mean exposure durations for the NASA1032 and NASA1035 raft trials were 483 and 514 minutes, respectively, and not significantly different. A further contributing factor to differences in exposure duration between these garments is the relatively early NASA1032 raft trial termination of subject NASA1 due to an irregular ECG. None of the other NASA parameters shown in Table 5 demonstrated any significant differences between the NASA1032 and NASA1035 trials.

The AF1034 provided 2 hour protection against the onset of hypothermia for all subjects when a raft was employed (Table 6). All but subject AF4, who had the lowest body fat in the AF study, were able to finish an AF1034 immersion trial without reaching a $T_{re} = 35°C$. Even so, AF4 came closer to completion time in the AF1034 immersion trial than in any of his AF1030 trials, and with only 3.5 minutes to finish, he came closer to the two hour specification time than any of the early-ending AF1030 trials. In contrast, all but one of the four subjects testing the AF1030 had at least one trial terminated because of low T_{re}. This one subject, AF3, had the highest body fat of any subject in the AF experiment (22.2%). Subject AF4, with the lowest (13.34%) body fat in the AF study, was not able to endure the 2 hours for either raft or immersion while wearing the AF1030. No statistically significant differences were observed between the AF1030 and AF1034 for any of the AF parameters listed in Table 6.

DISCUSSION

The correlation between physiological response to cold and body fat is demonstrated by the results of the NASA and AF studies. This relationship is demonstrated within the NASA study by the fact that the subject of lowest body fat, NASA1, responded the poorest (reached a $T_{re} = 35°C$) in the less protective NASA1035, and the two NASA subjects of highest % body fat always had the smallest drop in T_{re} over exposure period in both immersion and raft experiments. This same trend of increased cold tolerance with increased % body fat was seen in the AF trials. The subject of lowest body fat, AF4, had the most difficulty in keeping T_{re} above 35°C in both suits (*highest* ΔT_{re} and $\Delta T_{re}/t_T$ in 3 of his 4 trials), whereas the subject of highest body fat, AF3,

Table 5. Physiological data obtained from the NASA study.

SUBJECT	Core Temp Change (C)	Rate of Core Temp Change (C/minutes)	Perceived Shivering (7 = maximum)	Rank by % Body Fat (4 = highest)	Elapsed Time in water (minutes)	Reason for Termination (see report)
1032RAFTS						
NASA1	-1.79	-0.0051	3.00	1	353.0	*medical*
NASA2	-0.85	-0.0014	2.50	4	617.5	*low toe temp*
NASA3	-1.37	-0.0029	3.00	2	477.5	*subject request*
NASA4	-0.03	-0.0002	3.00	3	154.0	*subject request*
MEAN	-1.01	-0.0024	2.88		400.5	
SEM	*0.379*	*0.0030*	*0.125*		*98.3*	
1035RAFTS						
NASA1	-2.21	-0.0103	2.00	1	215.5	low core temp
NASA2	-1.00	-0.0015	4.00	4	659.0	*low toe temp*
NASA3	-1.30	-0.0020	1.50	2	666.0	*subject request*
NASA4	-1.76	-0.0034	2.50	3	517.0	*subject request*
MEAN	-1.57	-0.0043	2.50		514.4	
SEM	*0.265*	*0.0030*	*0.540*		*105.4*	
1032IMMS						
NASA1	-2.06	-0.0092	4.00	1	223.5	*low toe temp*
NASA2	-0.71	-0.0029	4.00	4	245.0	*low toe temp*
NASA3	-1.01	-0.0035	3.00	2	286.0	*subject request*
NASA4	-0.15	-0.0008	4.00	3	189.0	*subject request*
MEAN	-0.983	-0.0041	3.750		235.9	
SEM	*0.401*	*0.0030*	*0.250*		*20.3*	
1035IMMS						
NASA1	-2.40	-0.0128	4.50	1	187.0	low core temp
NASA2	-0.72	-0.0041	3.50	4	175.5	*low toe temp*
NASA3	-1.05	-0.0089	2.00	2	117.5	*low toe temp*
NASA4	-0.35	-0.0021	2.00	3	170.5	*subject request*
MEAN	-1.13	-0.0070	3.00		162.6	
SEM	*0.447*	*0.0030*	*0.612*		*15.4*	

Table 6. Physiological data obtained from the Air Force study.

SUBJECT	Core Temp Change (C)	Rate of Core Temp Change C/minutes	Perceived Shivering (7 = maximum)	Rank by % Body Fat (4 = highest)	Elapsed Time in water (minutes)	Reason for Termination (see report)
1030RAFTS						
AF1	-2.110	-0.0172	1.50	3	123.0	2 hour duration met
AF2	-3.410	-0.0304	1.00	2	112.0	low core temp
AF3	-0.560	-0.0046	1.00	4	120.5	2 hour duration met
AF4	-2.600	-0.0323	2.00	1	80.5	low core temp
MEAN	-2.170	-0.0211	1.38		109.0	
SEM	0.600	0.006	0.239		9.8	
1034RAFTS						
AF1	-0.980	-0.0082	1.00	3	120.0	2 hour duration met
AF2	-0.340	-0.0028	1.00	2	121.0	2 hour duration met
AF3	-0.710	-0.0059	1.00	4	120.0	2 hour duration met
AF4	-2.400	-0.0204	4.50	1	117.5	2 hour duration met
MEAN	-1.108	-0.0093	1.88		119.6	
SEM	0.450	0.004	0.875		0.7	
1030IMMS						
AF1	-3.210	-0.0329	2.50	3	97.5	low core temp
AF2	-1.020	-0.0091	5.00	2	112.5	subject request
AF3	-0.510	-0.0042	2.00	4	120.5	2 hour duration met
AF4	-2.180	-0.0287	4.00	1	76.0	low core temp
MEAN	-1.730	-0.0187	3.38		101.6	
SEM	0.605	0.007	0.688		9.8	
1034IMMS						
AF1	-1.300	-0.0108	2.00	3	120.5	2 hour duration met
AF2	-1.750	-0.0154	3.00	2	113.5	low toe temp
AF3	-0.980	-0.0081	1.50	4	120.5	2 hour duration met
AF4	-2.680	-0.0230	4.00	1	116.5	low core temp
MEAN	-1.678	-0.0143	2.63		117.8	
SEM	0.370	0.003	0.554		1.7	

Figure 2. Rectal temperature versus exposure time during immersion trials of the NASA 1032 suit. Each curve represents an individual subject.

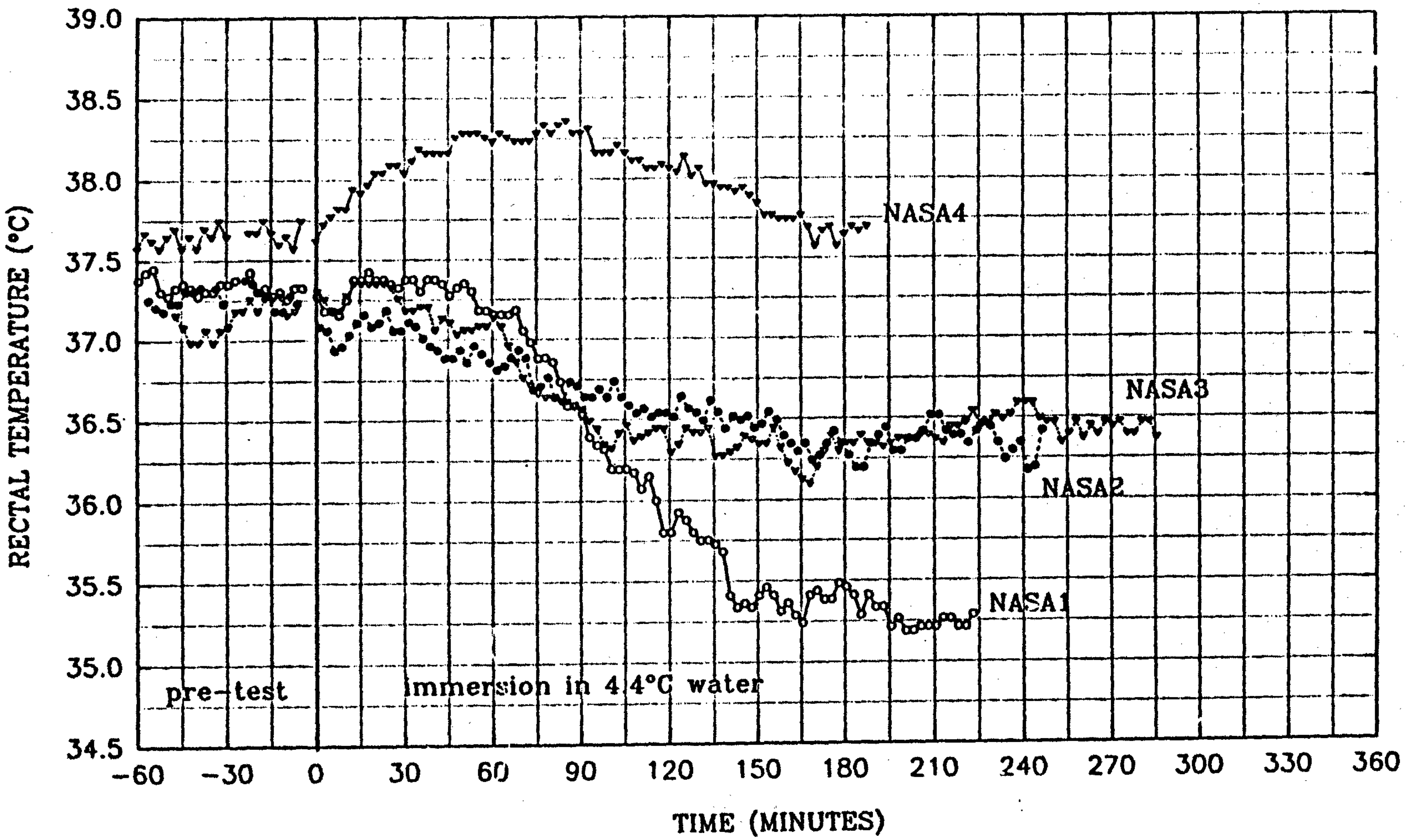

Figure 3. Rectal temperatures versus exposure time during immersion trials of the NASA 1035 suit Each curve represents an individual subject.

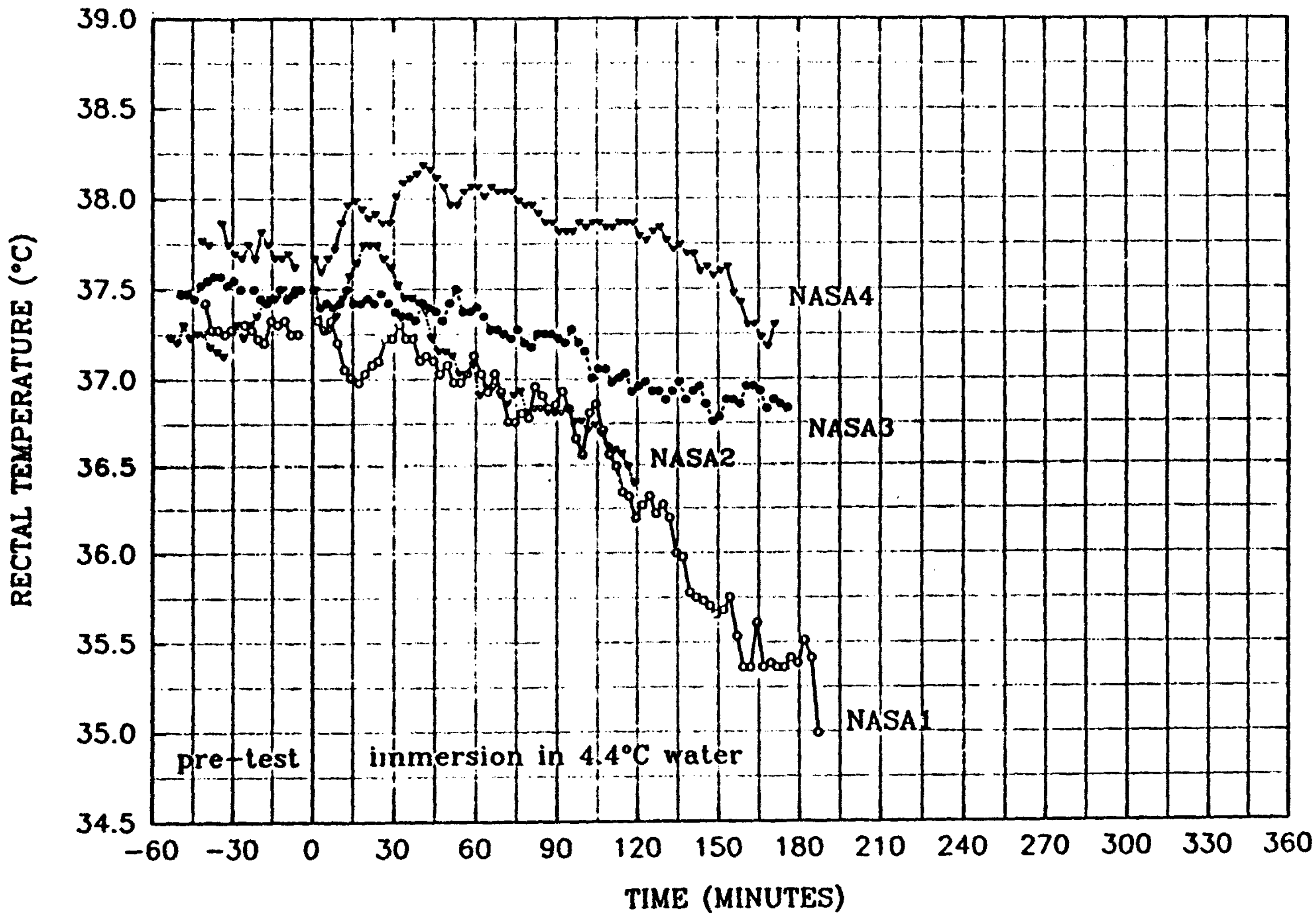

Figure 4. Rectal temperature versus exposure time during raft trials of the NASA 1032 suit. Each curve represents an individual subject. The sharp increase in temperature occuring between minutes 0–60 is probably a result of raft boarding and bailing.

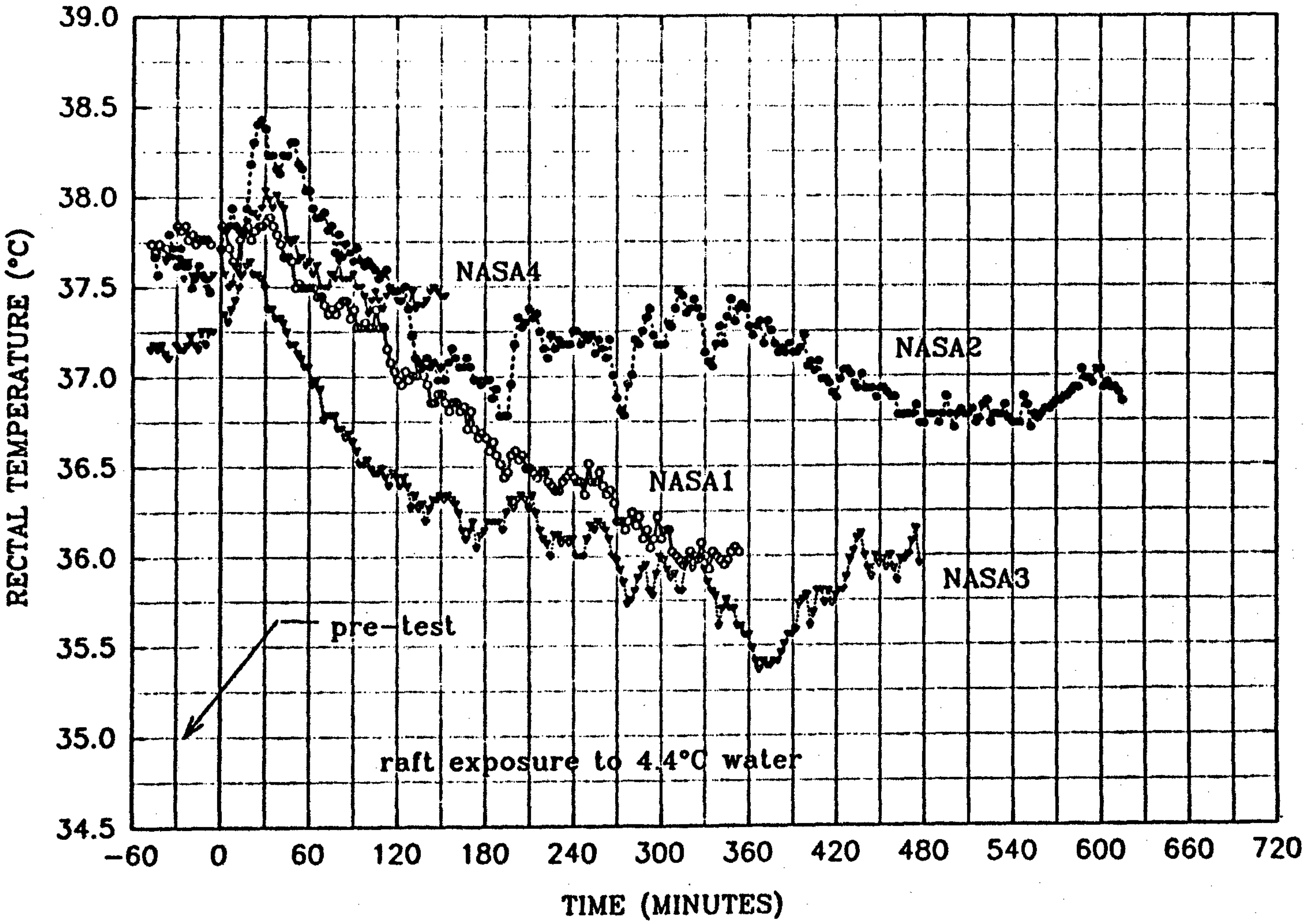

Figure 5. Rectal temperature versus exposure time during raft trials of the NASA 1035 suit. Each curve represents an individual subject. The increase in temperature between 0–60 minutes is probably due to raft boarding and bailing.

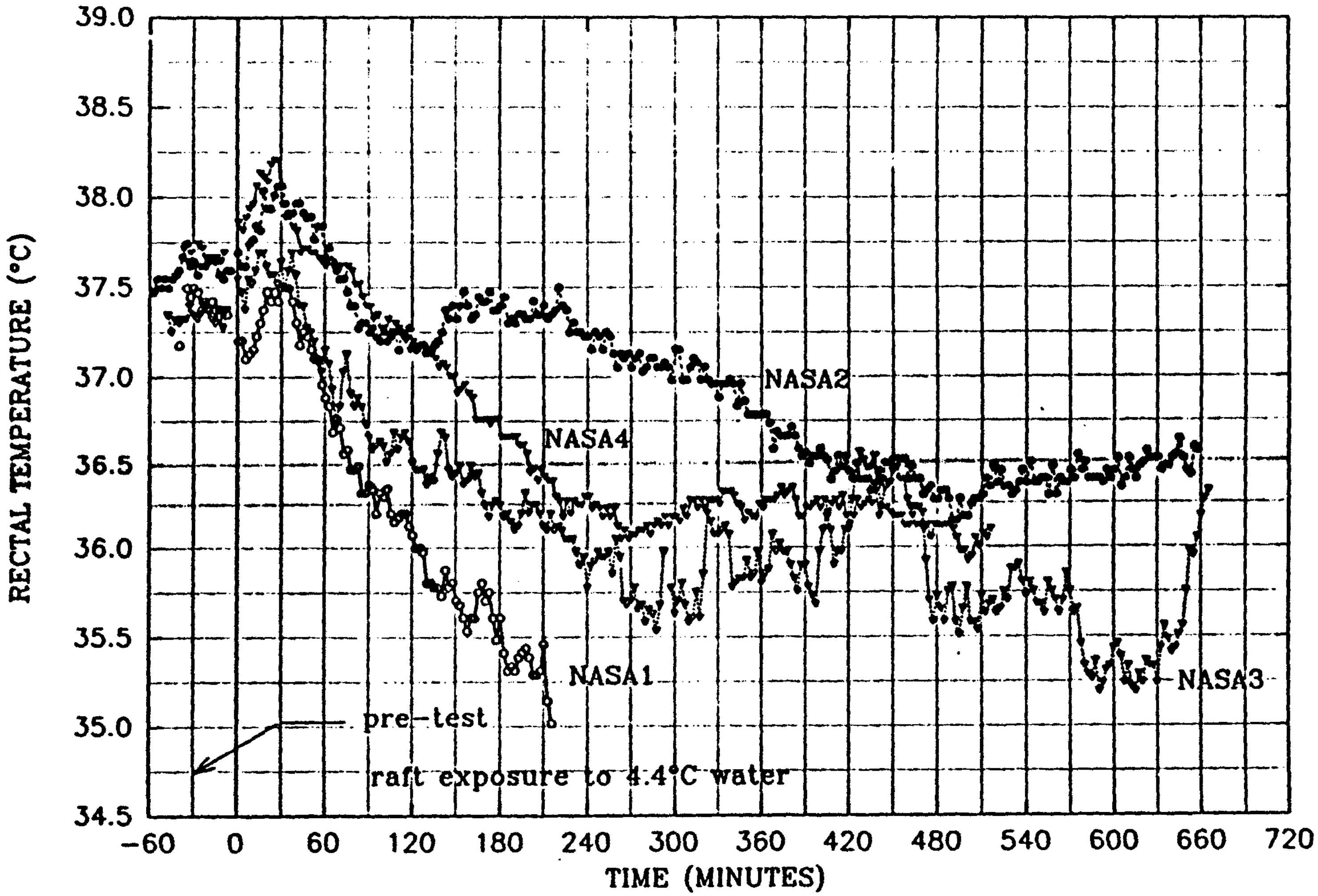

Figure 6. Rectal temperature versus exposure time for the AF1030 suit during immersion trials. Each curve represents an inidividual subject.

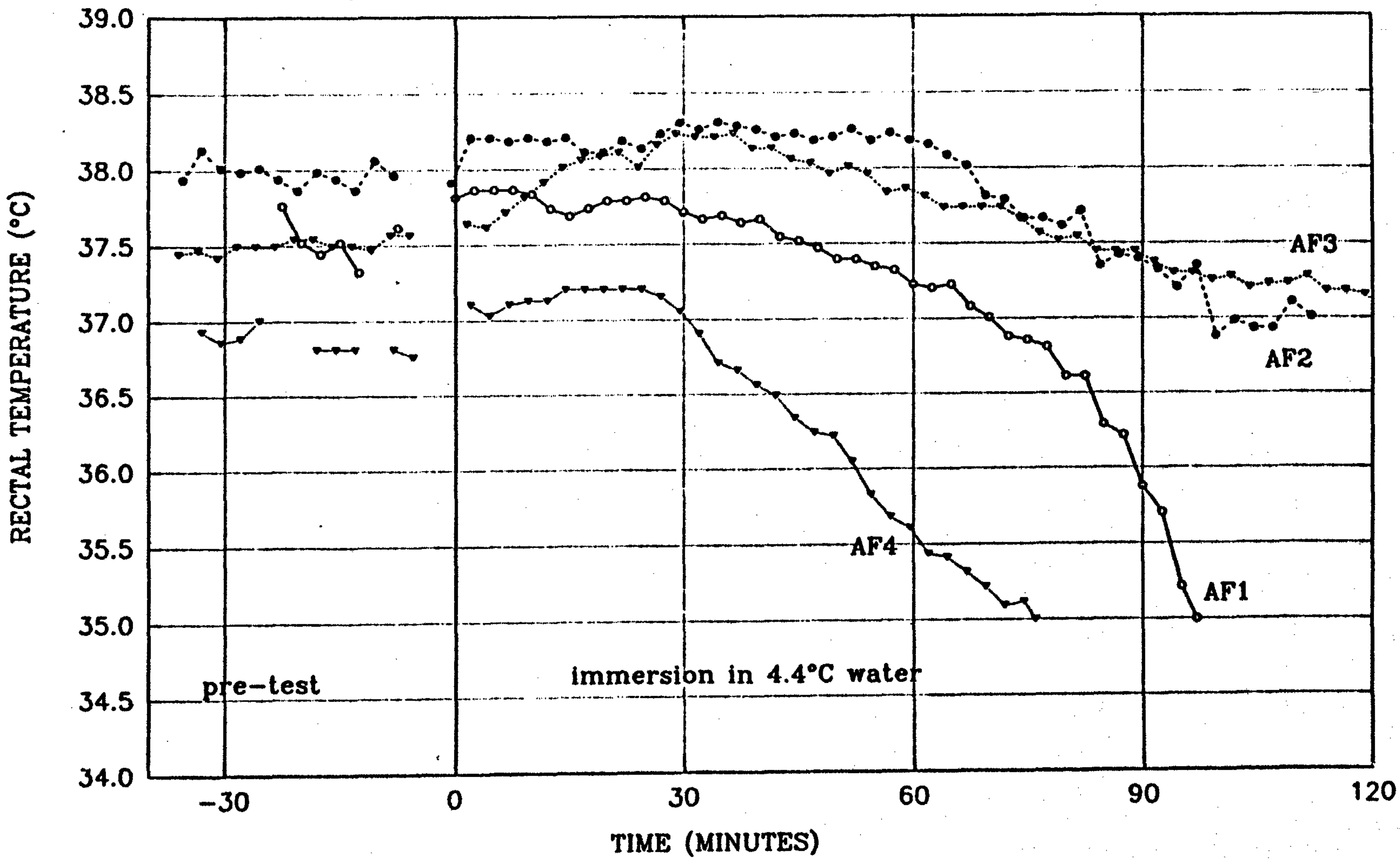

Figure 7. Rectal temperature versus exposure time for the AF1034 suit during immersion trials. Each curve represents an individual subject.

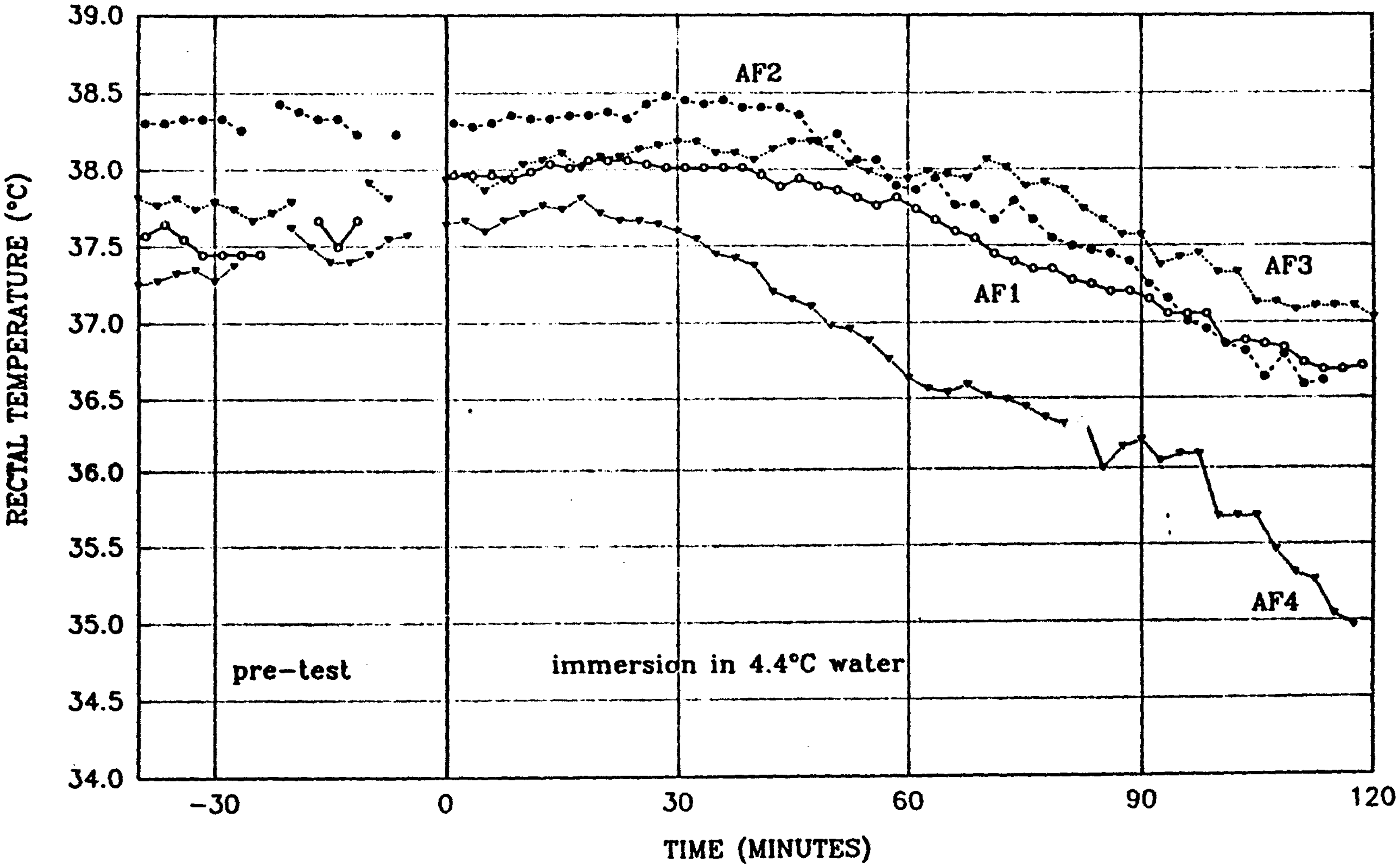

Figure 8. Rectal temperature versus exposure time during raft trials of the AF 1030 suit. Each curve represents an individual subject.

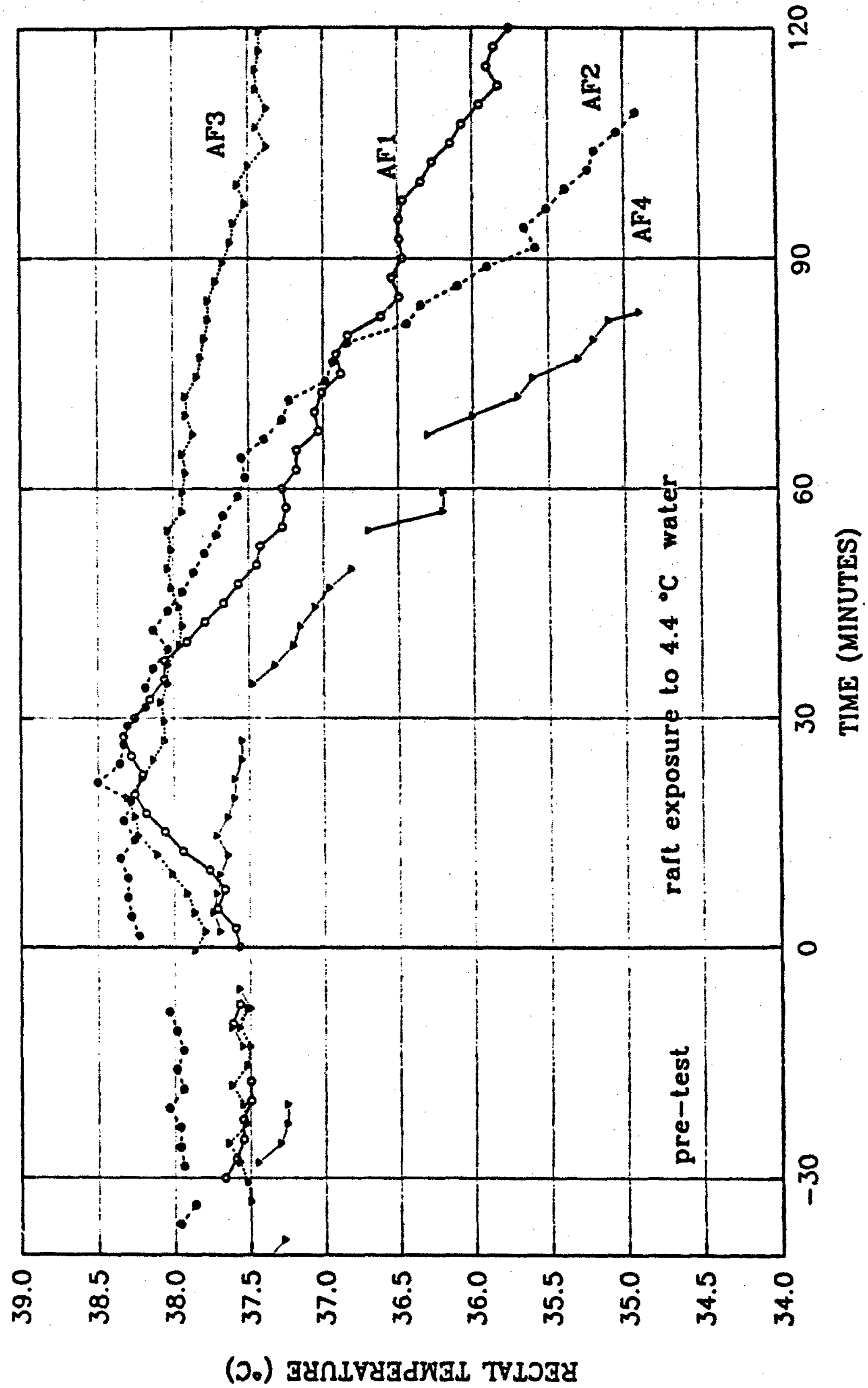

Figure 9. Rectal temperature versus exposure time during raft trials of the AF 1034 suit. Each curve represents an individual subject.

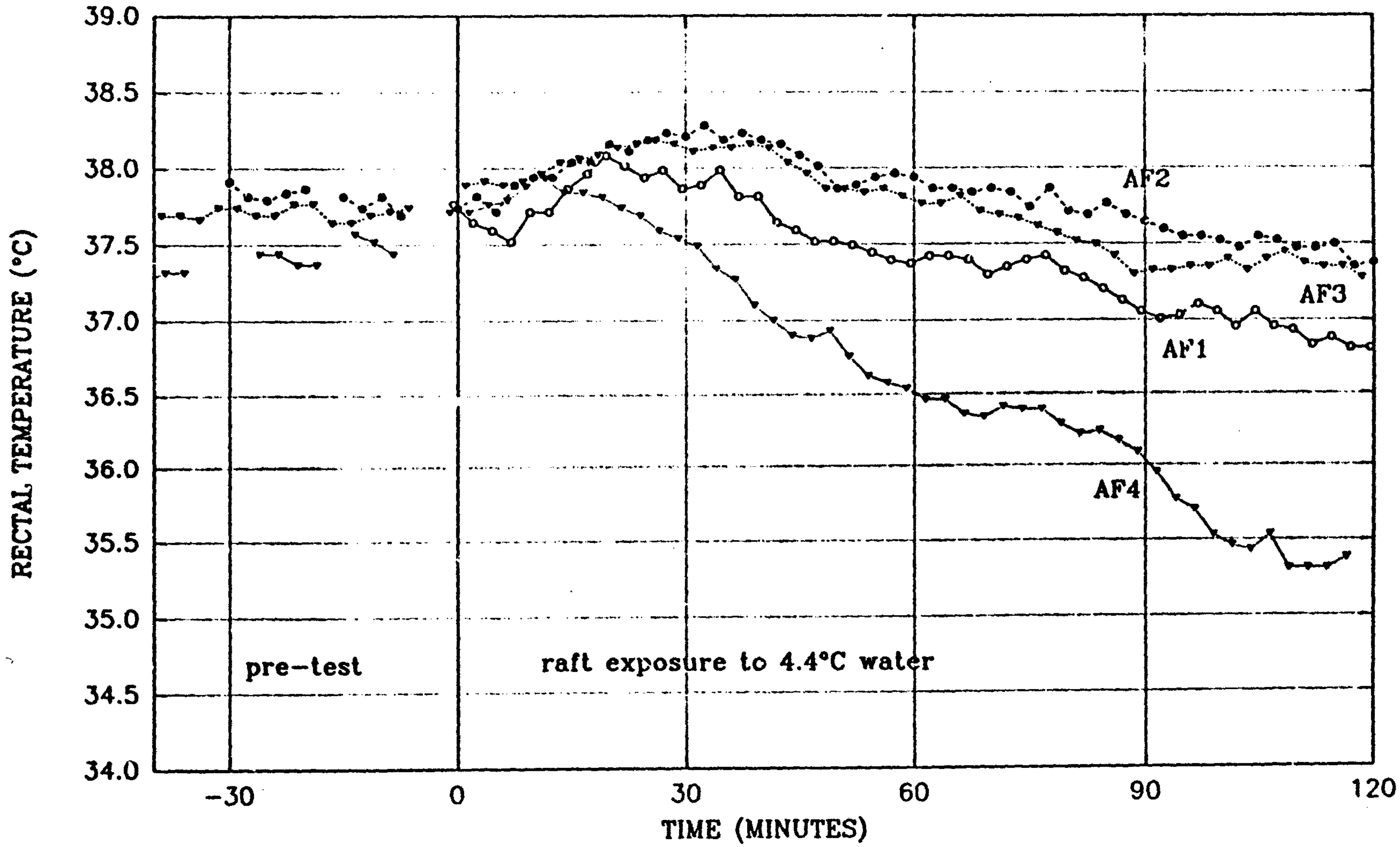

Table 7. Results of linear extrapolations of NASA data.

SUBJECT	Degrees Remaining Until Core = 35C (degrees C, from trial end)	Time Remaining Until Time Spec. (mins, from trial end)	Extrapolation to 35 C at 0.002 C Tre drop (total minutes)	Extrapolation to 35 C at 0.001 C Tre drop (total minutes)
1032RAFTS				
NASA1	1.1	1087	888.0	1423.0
NASA2	1.9	822.5	1547.5	2477.5
NASA3	1.0	962.5	977.5	1477.5
NASA4	2.6	1286	1439.0	2724.0
MEAN	1.6	1039.5	1213.0	2025.5
1035RAFTS				
NASA1	0.0	1224.5	210.5	205.5
NASA2	1.6	781	1459.0	2259.0
NASA3	1.2	774	1286.0	1906.0
NASA4	1.1	923	1067.0	1617.0
MEAN	1.0	925.625	1005.6	1496.9
1032IMMS				
NASA1	0.2	136.5	328.5	433.5
NASA2	1.4	115	930.0	1615.0
NASA3	1.3	74	956.0	1626.0
NASA4	2.6	171	1499.0	2809.0
MEAN	1.4	124.125	928.4	1620.9
1035IMMS				
NASA1	0.0	173	187.0	187.0
NASA2	1.8	184.5	1065.5	1955.5
NASA3	1.4	242.5	812.5	1507.5
NASA4	2.3	189.5	1330.5	2490.5
MEAN	1.4	197.375	848.9	1535.1

had no trouble with low T_{re} in any of his trials. AF3 had the *smallest* ΔT_{re} in 3 out of 4 of his trials.

The only deviation in this trend is an explainable one: subject NASA3 was an avid runner in very good physical condition, and although he was also relatively thin (14% body fat), he faired much better than a subject of similar body fat (NASA1 at 12% body fat), especially in the raft experiments. In fact, NASA3 logged the longest time of *any* subject in the NASA experiment while wearing the less protective NASA1035, with 566 minutes. It has been shown that a higher metabolic rate common in athletes can greatly enhance stability of core temperature in cold environments (10). It is also well known that metabolic rate, muscle mass and work capacity increase with physical conditioning, and may be a possible explanation for the large difference in performance between two subjects of similar body fat and surface area. An interesting follow-up experiment would be to further explore the relationship between cold tolerance and physical fitness as measured by metabolic rate.

The Air Force's suits have a specification of 2 hours of exposure duration because it is their perception that rescuers would be able to reach a downed pilot within this amount of time. NASA's requirements are more conservative; 24 hours exposure time with an operable raft, and 6 hours without the raft. The nature of the testing performed in this study only allow investigators to state how long a subject managed to tolerate these cold water experiments. Ultimately, however, the question we would like to address is whether the exposure duration specifications set by these organizations can be met. Specifically, would any of these suits be able to protect an individual from hypothermia for at least as long as specified in a real emergency scenario?

To address this question, we examined the trends in the data and attempted to make reasonable estimates of the time required to reach a core temperature of 35°C. For simplicity, linear extrapolations based on subjects' final T_{re} were used to bracket estimated performance. This type of prediction is fraught with possible errors, particularly since one assumes in these extrapolations that there is a steady state temperature decline and does not account for drastic changes in the physiological state of individuals over time. This is unrealistic, but serves in the present case to provide rough estimates of possible performance. Better estimates would depend upon reliable data for human cold exposures for up to 24 hours, which does not exist, and more complex modelling techniques.

For worst-case estimates we used the somewhat severe rate of temperature drop of -0.1°C/min, a rate typically observed in lightly clothed human volunteers during immersion in very cold water. This was used to address the question: "Given the actual performance of test subjects in a given suit, is the failure to meet the specification time *possible?* " If not, one could assume that an individual might avoid hypothermia for the specified time wearing the given suit. That is, if the extrapolated time at which T_{re} = 35°C meets or exceeds specifications, this extrapolation suggests there is a high likelihood that an individual wearing the given suit could avoid hypothermia within a specified amount of time. Unfortunately, unless a subject's T_{re} is above 38°C at the end of the trial, hypothermia, as defined by T_{re} = 35°C, is reached within 30 minutes with this extrapolation.

Using this type of inquiry, we are able to conclude that both of the AF immersion trials that ended before the 2 hour time duration would probably have met AF specifications. Both trials involved subject AF2, with his AF1030 trial ending 7.5 minutes early (final T_{re} = 37.1°C) due to subject request and his AF1034 trial ending 6.5 minutes early (final T_{re} = 36.6°C) due to low toe temperature. With these relatively high final T_{re}, it seems quite likely that

the subject would have been able to prevent the onset of hypothermia for the remaining few minutes.

Our data seems to indicate that individuals would be able to keep their T_{re} > 35°C for two hours in the AF1034 with a raft. Without a raft, some subjects, possibly those who are thinner or less physically fit, might encounter some trouble. Subjects had a harder time fighting the onset of hypothermia while wearing the AF1030. It was clear from the results of this study that at least some individuals would not be able to maintain their T_{re} > 35°C, with or without a raft, for 2 hours while wearing the AF1030. Only one subject, AF3, was able to endure the entire 2 hours without reaching a core temperature of 35°C while wearing the AF1030. This was probably the result of considerable water leakage into the suit during periods of immersion due to the AF1030 defective zipper.

None of the NASA trials ended with a high enough T_{re} or lasted long enough to make the above method of extrapolation reasonable. Therefore, we examined an extrapolation method which could be argued as giving estimates of an upper cutoff time (i.e., it is not likely that a subject would be able to endure beyond a given period, assuming a "best case" drop in core temperature). This yielded a hypothetical high estimate of how long an individual could keep his core temperature above 35°C in a given exposure. The rational is that these extrapolations err on the side of an overestimation of survival time in a given suit. Should an individual's projected core temperature at a given point in time be ≤ 35°C, then it is assumed there is a high likelihood that the given suit *will not* prevent hypothermia beyond that point.

Using the rationale described above, two rates of T_{re} drop, .002°C/min., given by Hayward and Keatinge as representative of "a state of heat balance" (11), and .001°C/min., were employed. These two rates coresponded to the smallest non-zero changes in T_{re} observed in this study. The rates were used to estimate the upper limits of time a subject could stay in a cold environment, assuming that these rates were less than or equal to anything that could be accomplished non-transiently (averaged over long periods). Based on these rates, if an extrapolation predicts that at a given time T_{re} ≤ 35°C then this suggests that an individual would *not* last in the suit up to the specification times.

Extrapolations for the NASA1032 and NASA1035 indicate that these garments may provide sufficient protection for some individuals to maintain T_{re} > 35°C for 24 hours with a raft, particularly at the lower rate (Table 7). Similarly, these garments may provide adequate protection for 6 hour immersions based on these extrapolations. This is not to say that these garments will protect all individuals, as clearly the NASA1035, with or without the raft, provided inadequate protection for subject NASA1 to maintain T_{re} ≥ 35°C for > 216 minutes. A contributing factor to the short exposures of subject NASA1 was probably that he was thin (12% body fat). However, subject NASA3 was comparably thin (14% body fat) and despite this had considerably longer exposures. The difference may be related to physical fitness or some more obscure factor. It should be borne in mind that asserting *anything* concrete about these extrapolations is problematic because of the assumptions upon which they are based.

CONCLUSIONS

NASA

1. The NASA1032 and NASA1035 seem to offer roughly equivalent protection against hypothermia when used with a raft. Some individuals maintained T_{re} ≥ 35°C for >10 hours when these garments were used in conjunction with a raft.

Extrapolations suggest that both garments may provide adequate thermal protection to enable some individuals to maintain $T_{re} \geq 35°C$ for 24 hours in a raft. Despite this, some individuals may have problems maintaining $T_{re} \geq 35°C$ for more than 15 hours when the NASA1035 and a raft are used in combination.

2. When used without a raft, the NASA1032 appears to provide greater protection against hypothermia than the NASA1035, enabling some subjects to maintain $T_{re} \geq 35°C$ for upwards of 3.5 hours. Not all healthy individuals, however, will be provided sufficient thermal protection from either the NASA1032 or the NASA1035 to enable them to maintain $T_{re} \geq 35°C$ for more than approximately 3 hours when immersed. Extrapolations suggest that both garments may provide adequate thermal protection to enable some immersed individuals to maintain $T_{re} \geq 35°C$ for 6 hours. However, some thin individuals may be at risk if these garments are required to provide 6 hours of thermal protection necessary to maintain $T_{re} \geq 35°C$ during immersion.

Air Force

1. The AF1034 suit seems to provide more protection from cold water hypothermia than the AF1030, especially when used with a raft. When used alone or with a raft, the AF1030 did not prevent half of the subjects' T_{re} from reaching 35°C. This is probably due to leakage in the AF1030 zipper.

2. Some thin individuals, such as AF4, cannot be assured of avoiding hypothermia before two hours has elapsed, except when the AF1034 is used in conjunction with a raft. The AF1034, when used alone, was unable to provide sufficient thermal protection to prevent such thin individuals' T_{re} from reaching 35°C. The AF1030 was inadequate to prevent such a T_{re} drop both with and without a raft.

3. Both the AF1030 and AF1034, with or without a raft, provide adequate thermal protection to enable subjects similar to AF3 (22% body fat) to avoid hypothermia within the 2 hour specification time.

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